THE FUNCTION OF THE ERECTORES SPINAE MUSCLES IN CERTAIN MOVEMENTS AND POSTURES IN MAN*

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The erectores spinae muscles are described by topographical anatomists as extensors of the trunk. Borelli (1710), Duchenne (1867) and Beevor (1904) asserted that they contract when the trunk is flexed from the upright position and so act as antagonists to gravity. Weddell, Feinstein & Pattle (1944) stated that the lumbar and thoracic sacro-spinalis muscles are easily relaxed with 'satisfactory positioning', but gave no details of postures in which this occurs. Akerblom (1948) reported briefly that the electromyogram of the lumbar sacro-spinalis muscle, in eight out of twelve subjects sitting in the sunken position (i.e. with full flexion of the trunk), showed practically no difference from the resting electromyogram. Allen (1948) stated that the erector spinae is quiescent when full trunk flexion has been reached from the orthograde position. Kelton & Wright (1949) found in two subjects that the erectores spinae muscles were electrically silent for long periods of time in the 'easy standing position'. Floyd & Silver (1950, 1951) described the action of the erectores spinae during 'straining' and in flexion and extension of the trunk.

The present paper describes the functions of the erectores spinae muscles in certain postures and movements and during weight-lifting, as studied in 150 human subjects by electromyographic, photographic and radiographic methods. A preliminary account of this work has been given in brief communications to the Anatomical and Physiological Societies during 1949–52.

METHODS

In most experiments surface electrodes were placed directly over the muscles in the lumbar region. Concentric needle electrodes were also used in order to record the activity of the deeper parts of the muscles. The action potentials were amplified and recorded with either a 4- or 6-channel Ediswan electroencephalograph.

* This paper includes material which formed part of a Ph.D. Thesis of the University of London (Silver, 1952).

Both ink-writer and cathode-ray oscillographs were used but we usually preferred the former. Although the frequency response of the ink-writer oscillograph is inferior there is no significant loss of electromyographic information in our application of the method (Floyd & Silver, 1952).

Types of electrode

(1) Surface electrodes

Disks of 10 mm diameter were cut from silver foil of 0·4 mm thickness and hammered into a dome of diameter 5–6 mm surrounded by a flat rim. A 1 mm hole was bored at the top of the dome, a flexible wire soldered to the outside of the rim and the electrodes electrolytically coated with silver chloride. Immediately before use the dome was filled with electrolyte jelly (Cambridge Instrument Co.): surplus jelly, and any air trapped in the electrode, escaped through the hole in the dome when the electrodes were pressed on the skin. The electrodes were retained in position by adhesive strapping.

The skin was cleaned and rubbed with electrode jelly to reduce inter-electrode resistance and so minimize extraneous electrical interference. This resistance was usually less than 20,000 Ω and sometimes only 5000–10,000 Ω.

Siting of electrodes. The electrodes were placed symmetrically in pairs over the most prominent parts of the thoraco-lumbar and lumbar erectores spinae muscles. We believe that the action potentials recorded under these circumstances came almost entirely from the erectores spinae muscles. Other muscles, lying within a short distance of the electrodes, which might possibly be the source of action potentials, are: the abdominal muscles, latissimus dorsi, trapezius, serratus posterior inferior, the quadratus lumborum, intercostal and psoas muscles; in the upper thoracic region, the rhomboids; and in the lower lumbar region, the glutei.

The problem of extraneous pick-up by the erectores spinae electrodes from these adjacent muscles was studied by observation of the action potentials when particular muscles were brought into action. In addition, monitor electrodes (surface or concentric needle) were placed on or in most of these adjacent muscles in different experiments during the course of this work. By these means it was shown that contraction of the abdominal muscles was not recorded by electrodes over the erectores spinae muscles. Similarly, trapezius and latissimus dorsi m. did not give rise to pick-up provided the arms and shoulders were not actively moved but allowed to hang down loosely under gravity. It was considered possible that action potentials might be picked up from the psoas muscle despite the intervening, poorly conducting vertebrae. During flexion of one hip, in the sitting position, there was no alteration in the action potentials recorded from the erectores spinae electrodes, thus ruling out unwanted pick-up from the psoas muscle.

(2) Needle electrodes

Concentric needle electrodes were used to study activity in the deeper parts of the erectores spinae muscles. As the range of pick-up of the concentric needle electrode is restricted to a few millimetres, it is impossible to be quite certain that the whole volume of a muscle as large as the erectores spinae is inactive at any moment unless a large number of needle electrodes are used simultaneously. This was not practicable in the present experiments. Hence, when we speak of the relaxation of the muscle in certain postures, we cannot be sure that there are not a few motor units in action; but, if there are, our explorations with a single needle have failed to reveal them.

The method employed for the exploration of the erectores spinae muscles by needle electrodes during full flexion was as follows. The subject performed the flexion movement with surface electrodes over the lumbar erectores spinae. When the position of muscle relaxation was reached the subject was asked to keep that position. The concentric needle electrode was then inserted, and the deeper parts of the muscle were explored for motor unit action potentials. This was not painful even when small flexion and extension movements were made about this 'critical' position.

Recording trunk posture

The activity of the erectores spinae muscles was correlated with posture, particularly the position of the trunk and head. The subjects were photographed and the moment of exposure signalled on the electromyographic record.

The pelvic inclination was measured with the Wiles pelvic inclinometer (Wiles, 1937). This measures the angle made with the horizontal plane by the line passing through the posterior superior iliac spine and the mid-point of the upper edge of the symphysis pubis. (This measure is different from that used by some workers who measure the angle between the horizontal plane and the pelvic inlet.)

Lateral X-ray photographs of the sacrum and lumbar vertebrae were taken in eight normal subjects (3 male, 5 female) to correlate the position of the intervertebral joints with the activity of the overlying erectores spinae muscles. Owing to the large X-ray dosage absorbed it was only possible to take a maximum of four exposures per subject. Surface electrodes were fixed over the erectores spinae muscles at the level of L3 on each side. The subject first sat on a chair and flexed the trunk until the electromyogram showed that the muscles were just relaxed. The first radiograph was taken in this position, i.e. Fick's round-back position (Fick, 1911). The subject then stood up and bent towards the ground, and another radiograph was taken in the 'critical' flexion-relaxation position. Radiographs were also taken at the 'critical' position during weight-lifting.

The X-ray tube was used at a distance of 1·5 m and the film exposed for 0·7 sec. With greater distances (used to reduce distortion) the subjects were unable to remain still during the long exposure required. The distortion introduced by the short tube-distance in these experiments is not serious, and is approximately the same for all radiographs. The radiographs were compared by superposition of the shadows of the sacrum. The outlines of the superimposed radiographs were traced for reproduction in Fig. 9.

Normal and clinical material

The forty-five normal subjects (35 male, 10 female) used for these experiments were in the age range 5–42 years; most were medical students in the age range 18–22 years.

In addition, a series of 105 out-patients was examined, chosen because they all complained of back-ache but otherwise unselected. Electromyographic records were made from them in the manner described in this paper. The results are discussed below only in so far as they have a direct bearing on the function of the erectores spinae muscles in normal subjects.

RESULTS

Easy standing and spontaneous swaying movements. The subjects wore shoes and stood with the heels close together in a spontaneous upright posture, looking to the front, with arms hanging loosely and comfortably at the sides. In most of the subjects the erectores spinae muscles were found to be slightly active, Fig. 1 (*a*) and photograph 1. In those in whom there was no activity in the spontaneously adopted stance, activity could be readily evoked by a small forward displacement of the head. Conversely, the activity could always be greatly reduced or abolished by means of slight backward movements of the hands, shoulders or head, or by swaying backwards from the ankle joint, as shown in Fig. 1 (*b*) and photograph 3.

The upright stance is not a fixed, rigid position. All subjects showed spontaneous variations in trunk muscle activity correlated with the small deviations from the position of balance, described by Hellebrandt (1938) as
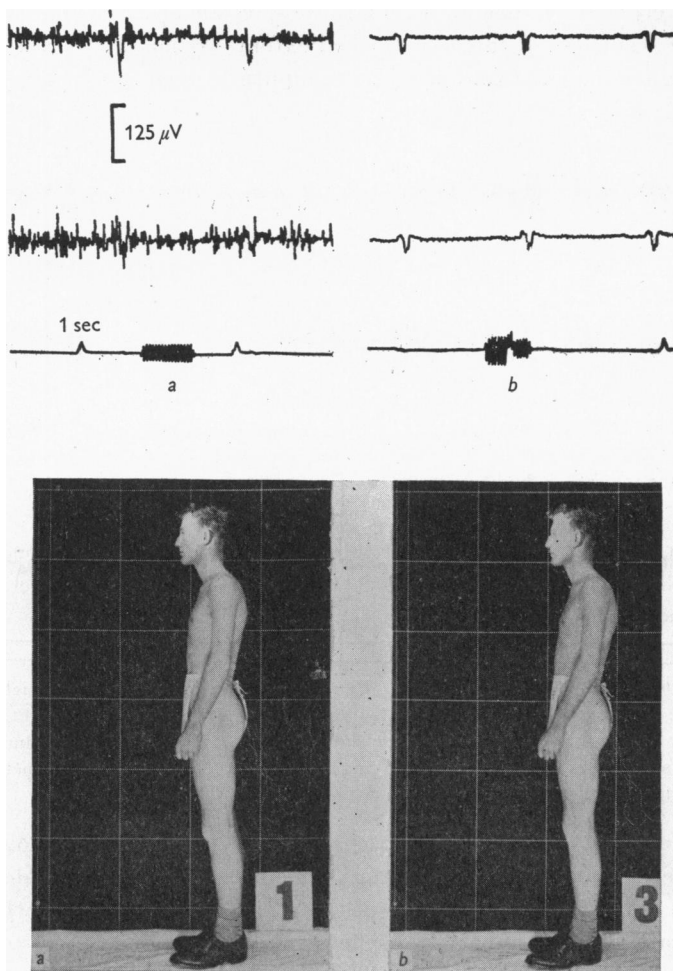
Fig. 1. Erectores spinae in standing upright. Electromyograms from left and right erectores spinae m. recorded between L2 and L4 vertebrae. Photographs 1 and 3 show the posture at the moments indicated by the signal marks in records (*a*) and (*b*), respectively. The grid in the background, seen in all the photographs, consists of 1 foot squares, and a plumb line is suspended to the left-hand side. Grid-camera distance, 20 ft.; subject-camera distance, 18 ft. In record (*a*) both erectores spinae m. are active. In (*b*) the muscles have relaxed, and only the e.c.g. is seen. The backward displacement of the c.g. of the body, due to this swaying movement, occurring mainly at the ankle joints, has resulted in relaxation of the erectores spinae m.

'movement upon a stationary base'. Fig. 2 shows the intermittent activity in the lumbar erectores spinae m. during these spontaneous swaying movements in a subject who showed this to a marked extent. When the eyes were closed the swaying movements were of greater amplitude and readily demonstrated electromyographically.
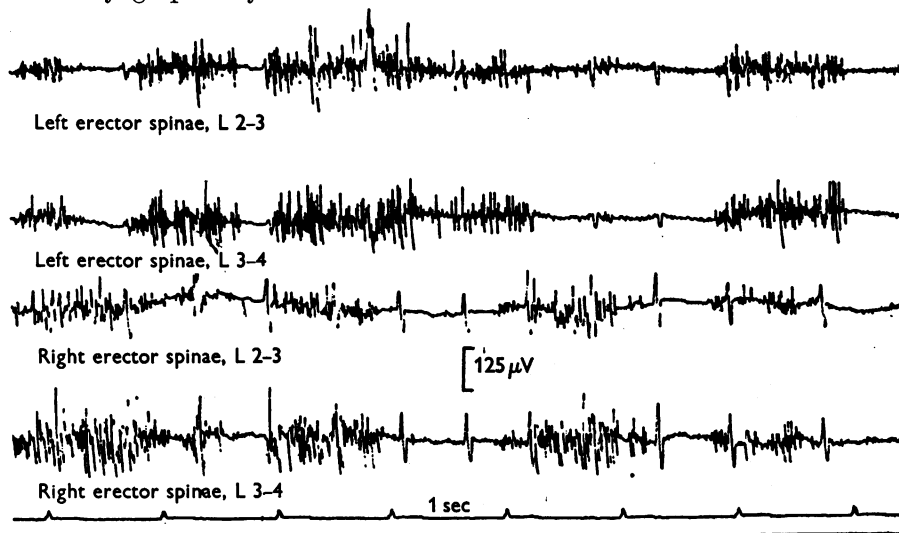

Fig. 2. Erectores spinae in standing upright. Electromyograms from the left and right erectores spinae m. at the levels of L 2–3 and L 3–4 vertebrae. Subject standing upright, in a spontaneously adopted posture between those shown in Fig. 1. The record shows fluctuations in activity associated with spontaneous swaying movements. Note also the asymmetry between left and right sides.

Initial movements of flexion and extension of the trunk. Fig. 3 shows a two-channel electromyogram of the erector spinae m. and the rectus abdominis m. on one side only. After adjustment of the position of the head, both muscles were in a state of minimum activity, the trunk being balanced between flexion and extension. At signal mark A the subject was told to bend backwards. There was a short burst of activity in the erector spinae m., which pulled the trunk backward and thereby displaced the centre of gravity of the trunk relative to the sacrum. The erector spinae m. now relaxed and extension of the trunk was continued by gravity under control of the rectus abdominis m. At signal mark B the subject was asked to bend forwards. The record showed an increase of activity in the rectus abdominis m. while the trunk was brought from the position of extension to the upright position. The flexion movement of the trunk was continued, but the rectus abdominis m. was now relaxed and the erector spinae m. contracted to control flexion. At signal mark C the subject arrested the flexion movement and extended the trunk to bring himself back again to the upright position.

Lateral flexion of the trunk. In lateral flexion of the trunk, from an upright stance in which the erectores spinae muscles showed slight activity, as in Fig. 1 (*a*), the activity of the contralateral erector spinae m. was increased and that of the ipsilateral muscle decreased. From the upright position of Fig. 1 (*b*) and photograph 3, lateral flexion resulted in activity of the contralateral erector spinae only. The erectores spinae m. on both sides remained inactive during lateral flexion of the trunk from an upright position with full trunk extension.
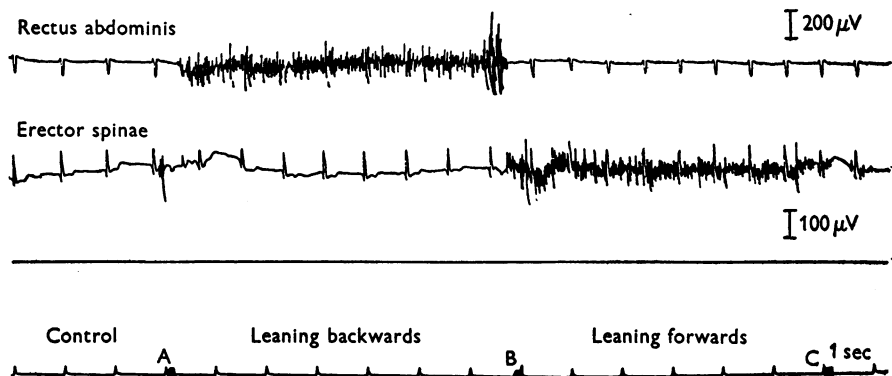

Fig. 3. Leaning backwards and forwards. Electromyograms from the rectus abdominis and erector spinae m., between L2 and L4, on the same side, recorded during flexion and extension of the trunk. Full description in text.

A weight held in one hand was equivalent to lateral flexion of the trunk in its effect on the erectores spinae: the contralateral muscle contracted. During unilateral weight holding, the activity of the contralateral erector spinae could be considerably reduced by lateral flexion of the trunk away from the side on which the weight was held. With an equal weight in each hand there was no asymmetry of erectores spinae action, and usually very little increase in activity over the resting, unloaded condition except when the subject stood with a pronounced stoop.

Straining and coughing. In straining there is simultaneous action of the erectores spinae and the external obliques with some involvement of the recti abdominis (Floyd & Silver, 1950). A similar pattern of activity was observed in coughing, singing and talking, in the upright stance. These are all activities in which the intra-abdominal pressure is raised and a forcible expiration made. Simultaneous contraction of these trunk muscles during straining and coughing was also found in other postures, e.g. in trunk flexion. Even in the position of full flexion when the erectores spinae m. were relaxed (see below) they contracted during the act of coughing, without visible change of the degree of trunk flexion.

Pelvic inclination. The normal pelvic inclination is about 30°, and this can be altered voluntarily within a range from about 20 to 40°. When the inclination was voluntarily increased there was an increase in erectores spinae m. activity, and, when decreased, a decrease in activity.

Full flexion. Fig. 3 shows that the erectores spinae m. contracted to control flexion of the trunk from the upright position. With increasing flexion the activity of the erectores spinae m. increased, so counteracting the increased gravitational moment of the head and trunk about the lumbar joints. Surprisingly, however, erectores spinae activity was suddenly reduced when the trunk reached full flexion (Fig. 4).

The subject started from the upright position of Fig. 1 (*a*) and bent forward to touch the ground. In record (*a*) of Fig. 4 the head was bent forward, the arms were hanging loosely down and flexion had occurred, principally at the hip joint. The lumbar lordosis was still visible. In record (*b*) the hands were 3 in. nearer the ground, some trunk flexion had occurred and the lumbar lordosis had practically disappeared. In (*a*) and (*b*) there was slight flexion at the knees. The electromyograms both showed considerable and continuous activity in the erectores spinae muscles. In record (*c*) the hands were a further 6 in. nearer to the ground and trunk flexion was greater. The activity of the erectores spinae m. had ceased, and only the e.c.g. complex disturbed the baseline. The erectores spinae m. remained inactive even with further bending brought about by increased hip flexion. In record (*d*) the subject had already begun to raise himself, and records (*e*) and (*f*) show further stages in the upward movement. In (*d*) the erectores spinae m. were still inactive, but in (*e*) the muscles were contracting, and in (*f*) contracting more vigorously. They continued to do so until the subject regained the upright posture.

In this experiment the position in which the activity of the erectores spinae m. ceased during the flexion movement lay between the two positions (*b*) and (*c*). During the extension movement activity recommenced between positions (*d*) and (*e*). Both (*d*) and (*e*) lay between (*b*) and (*c*), moreover both (*d*) and (*e*) were themselves close together. Hence the critical position for erectores spinae relaxation in the flexion movement approximated closely to the critical position for onset of erectores spinae m. action in the extension movement.

Anatomically, the erectores spinae muscles play no part in controlling hip flexion, and hence the relaxation of the erectores spinae m. observed in the flexion movement should be independent of hip flexion. This can be seen in Fig. 5. In record (*a*) the subject was standing in the fully flexed position with erectores spinae relaxed. Without alteration of the angle of flexion at the hip, the subject extended the trunk and the erectores spinae m. contracted vigorously, record (*b*). This is further illustrated in the sitting posture and will be referred to again.
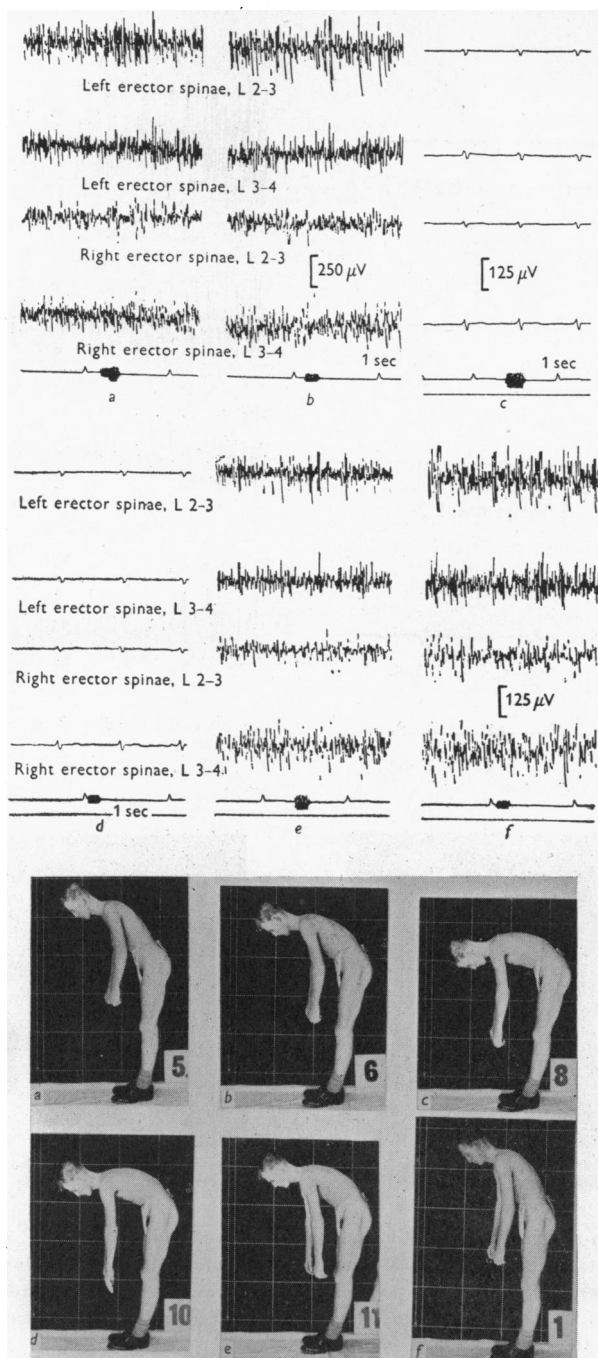
Fig. 4. Erectores spinae in trunk flexion. The figure shows six extracts from continuous electromyograms of the left and right erectores spinae m. at levels L 2–3 and L 3–4. The six photographs record the posture of the subject at the times indicated by the signal marks. The subject is bending down to the ground, as if to touch his toes, and returning to the upright position. Full description in text.
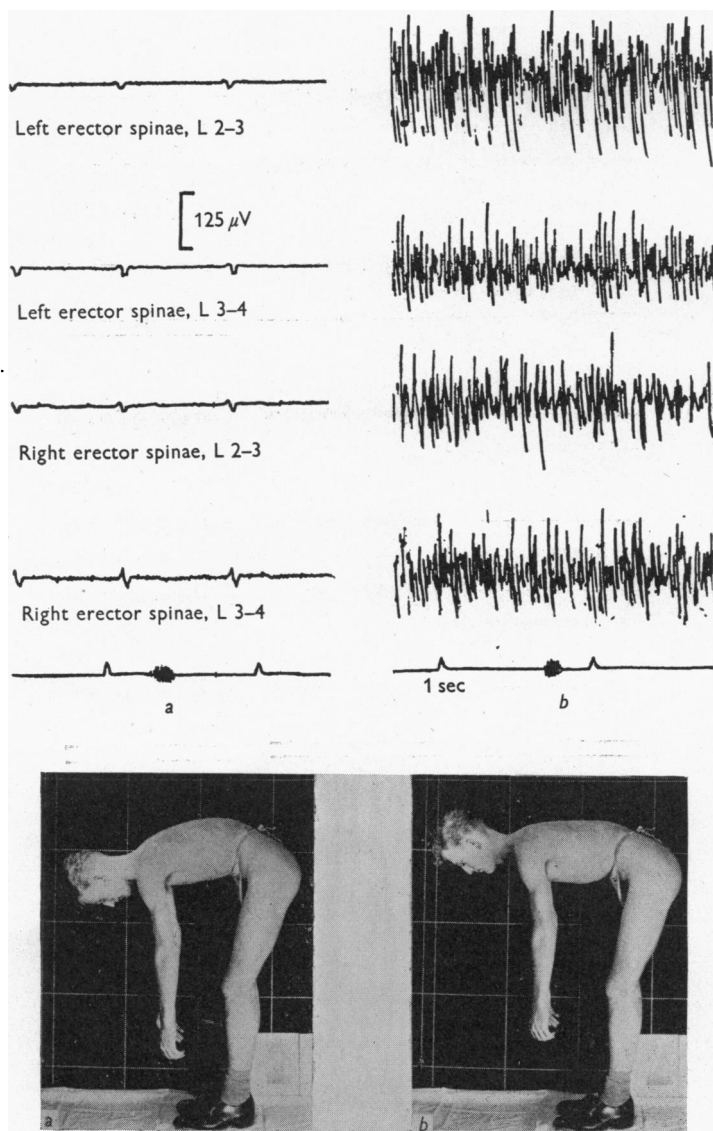
Fig. 5. 'Flexion-relaxation' of erectores spinae. Electromyograms from left and right erectores spinae m. at levels L 2–3 and L 3–4, with corresponding photographs. In (*a*) the subject is bending down in the fully flexed position. The erectores spinae m. are relaxed. In (*b*), without alteration of the angle of flexion of the hip, the subject voluntarily extended the trunk by contracting the erectores spinae m. See text.

Needle electrode recording. Fig. 6 shows four cathode-ray oscillograms of erector spinae m. activity taken from a subject in the standing position with the trunk bent forward in full flexion. In this experiment concentric needle electrodes were introduced to explore the muscle at different depths. The four records were taken at depths of 1, 2, 3 and 4 cm below the skin at a level midway between the spines of the 3rd and 4th lumbar vertebrae. During the exploration of the greatest depths the needle was only a few millimetres away from either the lamina or the ligamentum flavum. The subject allowed the trunk to bend forwards in the manner already described and the action potential discharge ceased. This relaxation was observed at all depths in the muscle. Simultaneous recordings obtained with surface and concentric needle electrodes showed that the relaxation occurred throughout the muscle.
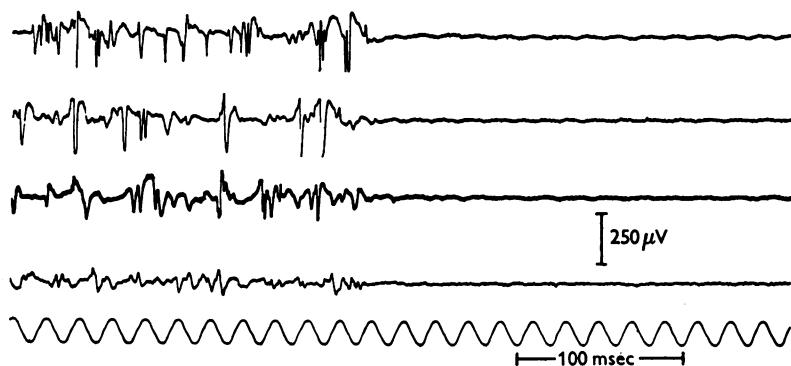

Fig. 6. 'Flexion-relaxation' of erectores spinae. Electromyograms of the erector spinae m. recorded with concentric needle electrodes at depths of 1, 2, 3 and 4 cm at the level L3. 'Flexion-relaxation' was found at all depths in the muscle.

Psoas major. The attachment of the psoas major m. to the front of the transverse processes and adjacent surfaces of the bodies of the lumbar vertebrae, behind the centre of the intervertebral disc, suggested that the muscle might extend the lumbar intervertebral joints, and hence that the psoas might 'take over' from the erectores spinae m. in the position of full flexion. A single experiment was performed to test this hypothesis. A long needle was introduced into the belly of the psoas m. at the level of L3 by the technique used in the infiltration of the lumbar sympathetic chain. Motor unit action potentials were observed both in the upright position and when the hip was flexed, but these disappeared in the movement of bending down to the ground once flexion of the hip joint had been initiated, and there was no activity while the erectores spinae were relaxed (Silver, 1952).

Weight lifting in full flexion. Fig. 7 shows two extracts from an electromyogram recorded while the subject bent to the ground, grasped a 28 lb. weight and lifted it. During the flexion movement the erectores spinae relaxed

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as previously described, and remained relaxed during the grasping and initial lifting of the weight as shown in Fig. 7 (*a*). When the weight was lifted an inch higher than in (*a*) the erectores spinae became vigorously active as shown in record (*b*) and the accompanying photograph. This activity continued with diminishing intensity until the upright position was reached. Thus the pattern of activity was similar to that found in flexion and extension without added weight.

A common variant of the pattern of activity with weight lifting is shown in Fig. 8. There was a burst of activity in the erectores spinae just as the weight was lifted off the ground. It lasted for a second or two. The activity then subsided, and a few seconds later the erectores spinae m. contracted vigorously and continued to do so until the subject once more reached the upright position. The burst of activity which coincided with the initial lifting movement was associated with the grunting or straining effort which many subjects made at the beginning of these lifting movements.

Sitting. In sitting upright in a chair without use of the back-rest the activity in the erectores spinae m. usually slightly exceeded that recorded when the subject was standing upright. Despite careful adjustment of the head and shoulders, some activity usually persisted until a position was reached which was unstable with the subject about to fall backwards.

In the photograph of Fig. 9 (*b*) the shoulders have been braced back, but activity persisted in the erectores spinae. When the subject allowed the trunk to flex fully, as shown in Fig. 9 (*a*), the erectores spinae m. relaxed.

The slumped position in sitting is reached from the upright position by simultaneous flexion of the vertebral column and *extension* of the hip joint. Hence the relaxation of the erectores spinae m. occurred in trunk flexion in the standing position with concurrent *flexion* of the hip joint, and in the sitting position with simultaneous *extension* of the hip joint. These observations reinforce the point made earlier that relaxation of the erectores spinae muscles is related to the degree of flexion of the vertebral column but is independent of flexion of the hip joint.

Radiography of vertebral column in 'flexion-relaxation' position. In all of the eight subjects examined radiographically, the degree of flexion of the vertebral column in the standing position was greater than the degree of flexion in the sitting position at the point when 'flexion-relaxation' occurred, as judged electromyographically. This is a statistically significant result, since the differences would all be in the same direction by chance only once in 2^7 ($=128$) times.

Fig. 10 shows the lateral X-ray appearance of the sacrum and lumbar vertebrae of two of the eight subjects. Subject A (male) showed the smallest difference of the series. Subject B (female) showed the greatest difference. No attempt has been made to express these differences quantitatively in terms of
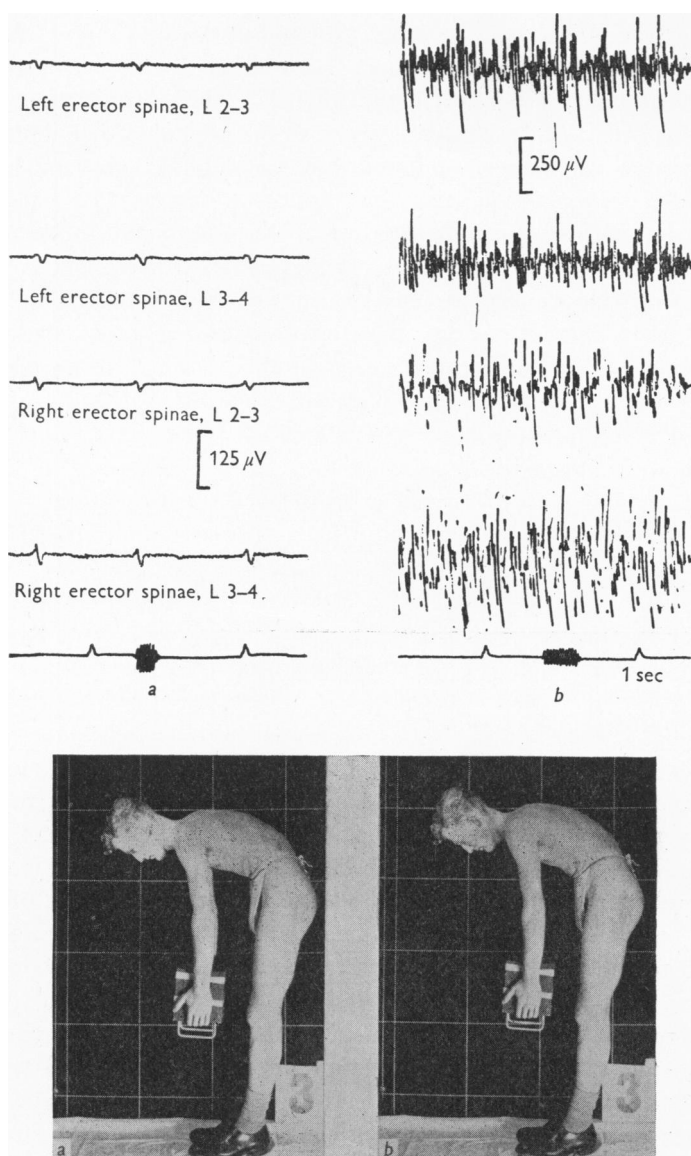
Fig. 7. Weight lifting. Electromyograms of erectores spinae m. on left and right sides, at levels L 2–3 and L 3–4, with corresponding photographs. The subject lifted naturally a 28 lb. weight from the ground, without contraction of the erectores spinae m. until the trunk reached a position intermediate between those shown in the two photographs. The initial lifting movement was brought about by extension of the hip joints (not illustrated electromyographically).

the angles between the upper surface of the sacrum and the lower border of
L1, because the precision of the method does not justify it.

Clinical studies. Table 1 summarizes the electromyographic findings on the
forty-five normal subjects together with the 105 patients. All subjects, normal
and pathological, could be placed into one of three groups. One hundred and
sixteen persons (including the forty-five normal subjects) showed the pheno-
menon of 'flexion-relaxation' in both standing and sitting positions (group I).
Of the remaining thirty-four, fifteen showed 'flexion-relaxation' sitting in the
slumped position but failed to show it in flexion from the standing position
(group II), and the remaining nineteen showed no relaxation in sitting or
standing (group III). Patients originally in group III progressed through
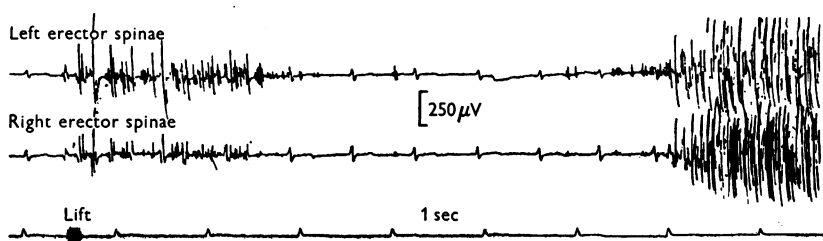group II to group I on full recovery (see discussion).

Fig. 8. Erectores spinae activity in weight lifting. Electromyograms from the erectores spinae m.
on left and right sides, showing a common variant in the pattern of activity during weight
lifting. Full description in text.

Effect of erector spinae m. injury. When the erector spinae m. is injured, as by
unaccustomed muscular exertion, there is pain and stiffness in the muscle
which is aggravated whenever the muscle contracts, e.g. when bending to the
ground, due probably to tearing of the interstitial skeleton (Hill, 1952). If the
patient could bend through the painful position into the position of full flexion,
the muscle relaxed and the pain lessened, although it did not always dis-
appear altogether.

DISCUSSION

'*Flexion-relaxation*' *of the erectores spinae m.* The electromyogram can be
interpreted quantitatively as a function of muscle tension (Haas, 1926;
Hoefer & Putnam, 1939; Seyffarth, 1941; Lippold, 1952; Bigland & Lippold,
1954). Coarser gradations of muscle action can readily be judged by eye from
the electromyogram (Floyd & Silver, 1950). In this way the electrical activity
of the erectores spinae m. in the upright position can be compared with the
activity during trunk flexion and in 'flexion-relaxation' in the same subject.
From Figs. 3 and 4 it is seen that the activity was markedly increased during
flexion from the upright position up to the point of onset of 'flexion-relaxation'.
From Figs. 4c, d, 5a, 6, 7a and 8 it is seen that the activity in the 'flexion-
relaxation' position (including weight-lifting) is less than that in the upright
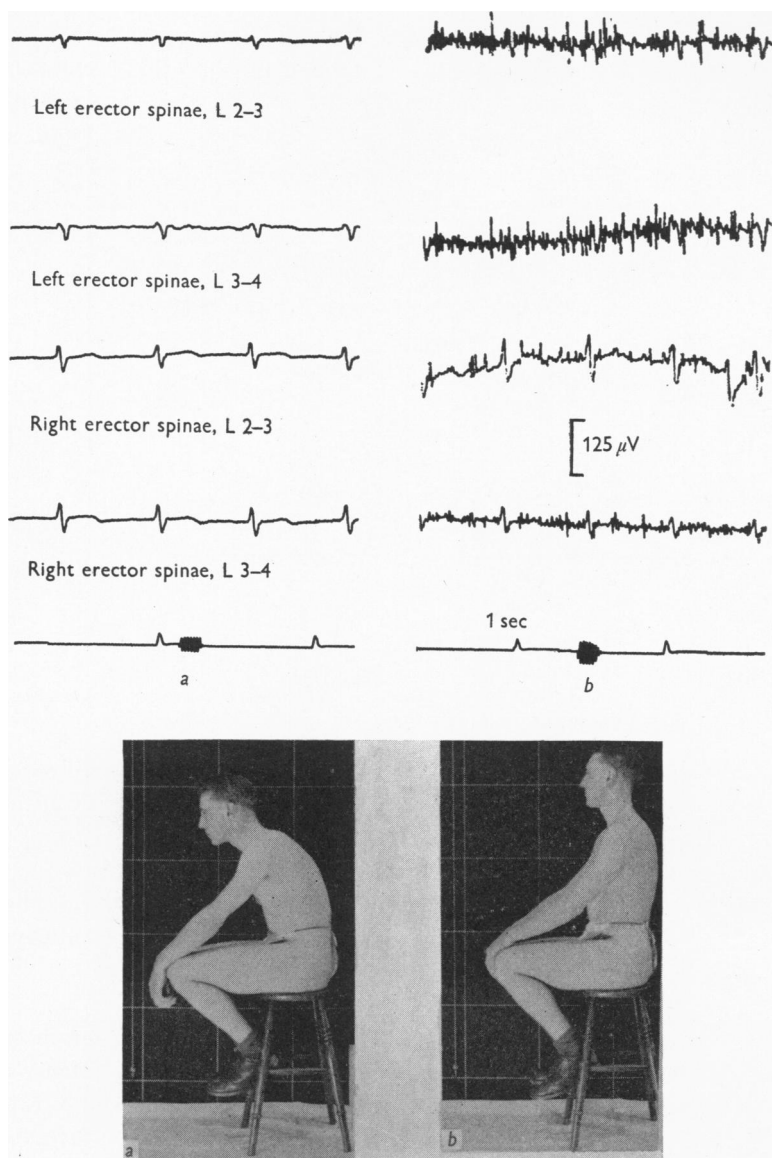
Fig. 9. 'Flexion-relaxation' of erectores spinae in sitting. Electromyograms of the erectores spinae m. at levels L 2–3 and L 3–4. In (*a*) the subject is sitting in the 'slumped' position, the vertebral column is fully flexed, and the erectores spinae m. are relaxed. In (*b*), when the subject sits upright, considerable activity is recorded.

position of Fig. 1*a* and is less than occurs in the correction of the small swaying movements shown in Fig. 2. These comparisons are particularly striking because the gravitational moment of the upper part of the body about

Subject A
Height 6 ft. 2 in.
♂

Subject B
Height 5 ft. 3 in.
♀

Broken line = full flexion, sitting
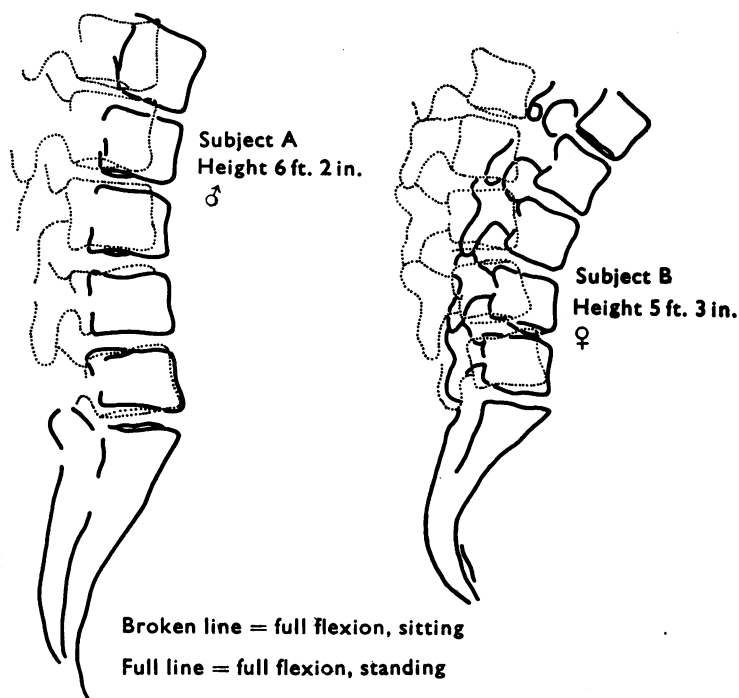
Full line = full flexion, standing

Fig. 10. Superimposed lateral X-ray photographs of the sacrum and lumbar vertebrae in the critical position of 'flexion-relaxation' in standing (full line) and sitting in the 'slumped' position (broken line) in two subjects. In the critical 'flexion-relaxation' position, a greater degree of flexion of the vertebral column occurred in standing than in sitting.

TABLE 1. 'Flexion-relaxation' in normal subjects and in patients complaining of back-ache

	Group I	Group II	Group III
Normal subjects	45	—	—
Patients complaining of back-ache	71	15	19
Total	116	15	19

Group I showed 'flexion-relaxation' in both sitting and standing positions (i.e. the normal response).

Group II showed 'flexion-relaxation' in sitting but not in trunk flexion from the standing position.

Group III showed no relaxation in trunk flexion.

the lumbar sacral articulation is greatest in the 'flexion-relaxation' position of Fig. 4, photographs 8 and 10, and least in the upright position, the ratio being possibly more than tenfold.

We found no evidence in our experiments to suggest that other muscles take over when the erectores spinae relax. The posterior part of the external oblique,

the quadratus lumborum and psoas muscles certainly do not become *more* active, and exploration of the deepest parts of the erectores spinae muscles in the thoraco-lumbar region by needle electrodes revealed no activity in the 'flexion-relaxation' position. Moreover, the mechanical advantage of these other muscles as possible extensors of the vertebral column is much less than that of the erectores spinae m., hence, if they should take over when the erectores spinae m. relax, they would be expected to contract vigorously and so facilitate electromyographic recording. All the electromyographic evidence, however, was negative on this point. It must be concluded therefore that, in full flexion of the trunk, when the erectores spinae m. relax, the relaxation takes place throughout the muscles including the deepest parts. Anatomical considerations suggest that the intervertebral ligaments, mechanically in parallel with the erectores spinae m., are the structures most likely to sustain the gravitational moment in the 'flexion-relaxation' position.

Lengthening reaction. In certain patients we found practically no movement of the intervertebral joints, although erectores spinae m. relaxation occurred on bending forward (achieved by hip flexion). Hence there was little or no lengthening of the erectores spinae muscle fibres during the movement, compared with the considerable lengthening which takes place in a normal subject. For example, a patient with advanced ankylosing spondylitis showed relaxation with practically no movement in the lumbar intervertebral joints. Lumbar osteotomy was performed a few days after electromyography, and, at operation, only the slightest flexion movement of the vertebral column was found to be possible. Normal relaxation was seen also in patients after spinal fusion. These observations suggest that the mechanism of erectores spinae m. relaxation in trunk flexion cannot necessarily involve a muscle lengthening reaction.

Transfer of tension from muscle to ligament during trunk flexion. The radiological evidence shows that, during flexion of the trunk, the points of attachment of the erectores spinae muscles and of the intervertebral ligaments are drawn apart. This has two consequences: (1) the muscle fibres lengthen, while exerting tension, and hence do negative work (Floyd, 1952), and (2) the tension in the ligaments increases.

The instantaneous state of the muscles can be represented by a point on their *length/tension* diagram (Fig. 11, curve M_D). There will be a corresponding *length/tension* curve for the ligaments but its shape is unknown and difficult to determine experimentally. Curve L in the figure represents the probable *length/tension* diagram of the ligaments and the relaxed muscles combined, regarded as a single element.

Curve F is the curve of total force necessary to counteract the gravitational moment at different degrees of vertebral column flexion from a given posture. It is one of a family of curves, each representing a different initial posture and other conditions, e.g. hip flexion or added load.

Curves L and F are shown as crossing over at the point P. The existence of such a cross-over point, within the range in which the muscle still exerts force, is necessary to explain the phenomenon of erectores spinae relaxation in trunk flexion. As long as the total force F is greater than the ligament plus relaxed muscle tension L, muscle action is required to maintain posture. When trunk flexion is increased so that the tension in the ligaments plus relaxed muscle is, by itself, sufficient to sustain the gravitational moment, muscle activity becomes unnecessary and relaxation must occur, otherwise extension of the trunk must commence.
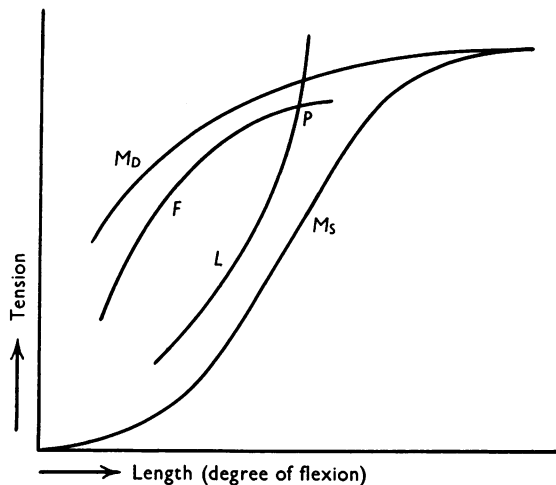

Fig. 11. Hypothetical *length/tension* diagrams for erectores spinae muscles and posterior ligaments of the vertebral column. M_S is the length/tension diagram of the relaxed muscle and M_D that of the maximally active muscle. L is the corresponding diagram for all the ligaments and the relaxed muscles taken together. Curve F is a typical curve of total force necessary to counteract the gravitational moment at different degrees of vertebral column flexion. P is the point where the ligament plus relaxed muscle tension curve L crosses the force curve F, i.e. the probable relaxation point for the erectores spinae m. (see text).

The difference between the ordinates of the two curves F and L in Fig. 11, for any given degree of trunk flexion, is the measure of the muscle tension required to maintain that degree of flexion as a static posture. The abrupt manner of onset of erectores spinae m. relaxation seen in the electromyograms suggests that these two curves meet to form a 'kurtotic beak' of the general shape shown in the figure.

Present knowledge does not enable us to decide whether the relaxation is brought about reflexly by an involuntary automatic adjustment of muscle action, or whether it might be more properly described as 'voluntary relaxation'. In both cases it is probable that reflexes involving muscle spindles and the small motor nerve fibre system play some part. A reflex inhibitory

mechanism triggered off by tension in the intervertebral ligaments was tentatively suggested by us to explain 'flexion-relaxation' (Floyd & Silver, 1951), but could not be confirmed by experiments in the monkey (Silver, 1952). Although there is therefore no direct evidence to support this hypothesis, there is some indirect support for it from the work of Boyd & Roberts (1953) on the stretch receptors in the knee-joint ligaments of the cat.

Flexion, sitting and standing. The difference between the degrees of vertebral column flexion at which relaxation occurred in the sitting and standing postures can be explained as follows. In sitting, in the slumped position, the trunk is mainly upright, although the vertebral column is flexed. The moment of the trunk, head and arms about the lumbar sacral articulation will be small. A relatively small force will be sufficient therefore to counterbalance this moment. Hence a small degree of flexion of the joints will produce sufficient tension in the ligaments for 'flexion-relaxation' to occur. In bending forward from the standing position, however, the moment will be much greater. Thus, greater tension in the ligaments will be required to counterbalance this moment in the absence of muscle action. Therefore the intervertebral joints will be more flexed when 'flexion-relaxation' occurs in this posture.

Rupture of the annulus fibrosus. It is therefore reasonable to suppose that the intervertebral ligaments play the dominant role in the maintenance of stability of the fully flexed vertebral column. In this position the ligaments are under considerable tension (Bradford & Spurling, 1945) shared between the ligamenta flava and the other less elastic ligaments such as the supraspinous and interspinous ligaments and, of especial interest, the posterior part of the annulus fibrosus. This probably accounts for the frequent injuries to the back, including rupture of the annulus fibrosus, which occur when the trunk is flexed (Middleton & Teacher, 1911; Bradford & Spurling, 1945; Friberg & Hirsch, 1949; *Lancet*, 1951). A sudden increased strain, in lifting a weight or extending the hip joint, may result in the rupture of one of these ligaments.

Our records show that the initial extension movement in weight lifting usually takes place at the hip joints, and that the erectores spinae m. remain relaxed or almost so, thereby placing the load on the ligaments. Heavy weights should, therefore, be lifted by some other method, e.g. with knees and hips flexed and the trunk as upright as possible, a position in which the load is shared by the erectores spinae m., and therefore one which avoids development of excessive tension in the inelastic intervertebral ligaments. The ability of the intervertebral ligaments to maintain posture, desirable though it may be in saving the activity of the extensor muscles, incurs its own penalties, since these ligaments seem to be injured more frequently than other ligaments in the body including the ligaments of the knee joint.

The findings in patients are consistent with the view that, when the intervertebral ligaments have suffered only a minor degree of injury, the tension

required to maintain trunk posture in the slumped sitting position can be sustained by the ligaments without pain and further injury. When, however, the strain on the ligaments is increased, by flexion from the standing position, the injured ligaments are unable to sustain the increased tension without pain and further injury; consequently the erectores spinae m. contract vigorously throughout the flexion movement. This interpretation is supported by our observations on patients, originally in group III, who progressed through group II to group I on full recovery (see Table 1).

SUMMARY

1. The action of the erectores spinae m. in the lumbar region was studied in 150 human subjects by electromyographic techniques with surface and concentric needle electrodes. Posture was recorded by photography, by measurement of the pelvic inclination and by radiography of the lumbar vertebrae and sacrum.

2. Most subjects showed a low level of discharge in the erectores spinae m. in the upright position. Small adjustments of the position of head, shoulders or hands could be made so as to reduce this resting discharge to a minimum or zero.

3. From the upright position, extension of the trunk is usually initiated by a short burst of erectores spinae m. activity and controlled by the rectus abdominis m. Flexion of the trunk from the position of extension is initiated by a burst of activity in the rectus abdominis m. and then controlled by the erectores spinae m.

4. In the upright position the contralateral erector spinae m. contracts in lateral flexion of the trunk except when the initial position is one of extension, when the erectores spinae m. are relaxed throughout the movement.

5. The erectores spinae m. contract synergically in straining and coughing, whatever the posture of the trunk.

6. In full trunk flexion the erectores spinae m. relax completely ('flexion-relaxation' of the muscle). 'Flexion-relaxation' occurred in 116 out of 150 subjects. Of the remaining 34, various pathological conditions prevented relaxation.

7. 'Flexion-relaxation' also occurs in weight lifting with the trunk fully flexed.

8. The mechanics of trunk flexion and 'flexion-relaxation' are discussed. With increasing flexion there is increase of tension in the intervertebral ligaments until the flexed trunk is supported by the ligaments, at which point the erectores spinae m. relax. The mechanism by which the relaxation is achieved is unknown. It is not a muscle lengthening reaction nor a reflex inhibition from intervertebral ligaments.

9. These findings explain the observation that rupture of the annulus fibrosus and other intervertebral ligaments commonly occurs in trunk flexion.

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